NOTE: FS review of the cited references are shown in italics in blue color *2-22-2018*

Changes in headwater streams can increase temperature in downstream reaches.

"Because heat added to a stream is not readily dissipated. Temperature increases in small headwater streams can increase the temperature regimes of downstream reaches. The magnitude of downstream effect depends on the relative increase in temperature and amount of streamflow from the exposed tributaries."

Beschta, R.L., Bilby, R.E., Brown, G.W., Holtby, L.B., and Hofstra, T.D. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. *In* Streamside management: forestry and fishery interactions. *Edited by* E.O. Salo and T.W. Cundy. Institute of Forest Resources, University of Washington, Seattle, Wash. pp. 191–232.

Changes in stream temperature take approximately 15 years to return to preharvest levels.

"Stream temperatures returned to preharvest levels in WS 1 approximately 15 years after clear-cutting, coinciding with canopy closure in the riparian zone."

Johnson, Sherri and Jones, Julia. 2000. Stream Temperature Responses to Forest Harvest and Debris Flows in Western Cascades, Oregon. Canadian Journal of Fisheries and Aquatic Sciences 57(S2):30-39
Watershed 1 (WS1) (250 acre watershed) was 100% clearcut (no roads) in 1962 and 1966, riparian areas cut and some wood removed from the channel.
WS3 was 25% patch cut plus 1.6 miles of road then experienced debris flow which took out riparian veg

Both were reveged with herbaceous within 10-20 years and tree cover within 30 years…Stream and soil temps measured

'This study highlighted the importance of solar radiation as a primary driver of stream temperatures and the increased influence of radiation when riparian vegetation was removed, either by clear-cutting and burning or by debris flows. The direct mechanism by which solar radiation warms exposed stream water and soils is radiative exchange (Brown 1969; Monteith and Unsworth 1980).

Conduction between water and alluvial substrates is often underestimated as an important mechanism influencing stream temperature (Brown 1969; Beschta et al. 1987), and

In forest gaps or disturbed riparian areas, direct solar radiation increases the temperature of soils and alluvial substrates that could conduct heat to the streams (Hondzo and Stefan 1994; Evans et al. 1995). Conduction from alluvial substrates might explain the observed increases in minimum stream temperatures after forest harvest."

Increases in stream temperature following harvest may not be limited to increases from loss of shade. Other factors include ground water, stream area, and hyporheic exchange.

"Temperatures of small streams can vary spatially and show mixed warming and cooling patterns, even when well shaded (Dent et al., 2008). Hypothesized sources of variation in small stream temperature include interaction with groundwater (Dent et al, 2008) and the influence of stream surface area and hyporheic exchange (Pollock et al., 2009). Pollock et al. (2009) in particular stressed that factors in addition to the condition of riparian canopy may affect stream temperature."

Janisch, Jack E.; Wondzell, Steven M.; Ehinger, William J. 2012. Headwater stream temperature: interpreting response after logging, with and without riparian buffers, Washington, USA. Forest Ecology and Management. 270: 302-313.
From Dent 2008: Stream and riparian attributes that correlated with observed temperature patterns included cover, channel substrate, channel gradient, instream wood jam volume, riparian stand density, and geology type. We observed a wide range of stream temperature conditions and spatial patterns prior to harvest. This is appropriate as greater canopy cover can be a significant predictor of cooler stream temperatures. However, the inherent complexity in small streams observed in this study indicates that additional processes may determine stream temperature conditions and patterns

when shade and canopy cover are consistently high. Given the potential influence of substrate and streamflow on temperature patterns in small streams, future studies should consider precise measures of substrate, streamflow, and/or hyporheic exchange. An examination of ground-water-surface water interactions in small streams may explain if this interaction has a modifying affect on harvest response. Given the observed variability in temperature patterns and correlations between temperature and stream characteristics, postharvest evaluations will need to account for inherent variability observed prior to harvest.

Pollock 2009*: Western WA study based on 0-100% basin wide harvest including riparian areas…anywhere there was extensive basin harvest, there was extensive riparian harvest…summary of study was that the combo of amount of basin and riparian harvest correlated with increases in stream temperature. Also debris flows caused by harvest contributed to channel widening and likely increases in temp. Causal relation between channel widening and shallowing from harvest including wider canopy openings over the channel, can lead to temp increases, loss of LWD and alluvium which reduces hyporheic storage and retention times*

If hyporheic exchange is an important factor that keeps surface waters cool, as has been demonstrated elsewhere, then to the extent that debris flows and past harvest of headwater riparian forests have removed current and future sources of instream LWD along with the alluvium that is stored behind LWD, recovery of natural temperature regimes in some streams may take centuries

Janisch: Study area was below 1,200' elevation, 5-22 acres…full clearcut, continuous buffer (30-45' buffer) and patch buffer (150-300' long, 30-45' width)…These analyses showed that the amount of canopy cover retained in the riparian buffer was not a strong explanatory variable. Instead, spatially intermittent streams with short surface-flowing extent above the monitoring station and usually characterized by coarse-textured streambed sediment tended to be thermally unresponsive. In contrast, streams with longer surface-flowing extent above the monitoring station and streams with substantial stream-adjacent wetlands, both of which were usually characterized by fine-textured streambed sediment, were thermally responsive. Overall, the area of surface water exposed to the ambient environment seemed to best explain our aggregate results. Results from our study suggest that very small headwater streams may be fundamentally different than many larger streams because factors other than shade from the overstory tree canopy can have sufficient influence on stream energy budgets to strongly moderate stream temperatures even following complete removal of the overstory canopy.

Especially important is surface area of the stream and associated wetlands. Substrate texture also appears to be important, likely because it indicates strength of stream–groundwater interactions which can substantially buffer the thermal regimes of small streams

Harvest on headwater streams can have cumulative effects and cause significant warming at the mouth of a watershed.

"The potential for cumulative effects associated with warming of headwater streams is a significant management concern. Beschta and Taylor (1988) demonstrated that forest harvesting between 1955 and 1984 in the 325 km2 Salmon Creek watershed produced substantial increases in summer water temperature at the mouth of the watershed."

In snow melt dominated catchments, partial retention buffers may not be adequate to prevent stream temperature increases.

"Two studies in snowmelt dominated subboreal catchments examined stream temperature response to harvesting with partial retention buffers, both conducted as part of the Stuart-Takla Fish-Forestry Interaction Project in the central interior of BC (Mellina *et al.*, 2002; Macdonald *et al.*, 2003b). Macdonald *et al.* (2003b) reported maximum changes in mean weekly temperatures that ranged from less than 1°C to more than 5°C for a set of streams subject to a range of forestry treatments."
Macdonald: increased temps caused by windthrown buffers…canopy openings…60-90' partial cut buffers (large trees removed)… Five years after the completion of harvesting treatments, temperatures remained four to six degrees warmer, and diurnal temperature variation remained higher than in the control streams regardless of treatment. Initially, the high-retention treatment acted to mitigate the temperature effects of the harvesting, but 3 successive years of windthrow was antecedent to reduced canopy density and equivalent temperature impacts

Moore, R. Dan., Spittlehouse, D. L. and Story, A. (2005), RIPARIAN MICROCLIMATE AND STREAM TEMPERATURE RESPONSE TO FOREST HARVESTING: A REVIEW[1]. JAWRA Journal of the American Water Resources Association, 41: 813–834. doi:10.1111/j.1752-1688.2005.tb03772.x.

Although there is ongoing research on the thermal response of ground water to forest harvesting (Alexander et al., 2003), no published research appears to have examined ground water discharge and temperature both before and after harvest as a direct test of the ground water warming hypothesis.

Several studies have shown that hyporheic exchange creates local thermal heterogeneity in larger streams (e.g., Bilby, 1984; Malard et al., 2002), and recent studies suggest that it can be important in relation to both local and reach scale temperature patterns in headwater streams (Johnson, 2004; Moore et al., 2005). However, there are significant methodological challenges associated with quantifying rates of hyporheic exchange and its influence on stream temperature (Kasahara and Wondzell, 2003; Story et al., 2003; Moore et al., 2005).

Small streams will be more heavily shaded by riparian vegetation and near stream terrain, will have a higher ratio of ground water inflow in a reach to the total downstream flow, and are located at higher elevations and thus experience a generally cooler thermal environment. However, local deviations from a dominant downstream warming trend may occur as a result of ground water inflow, hyporheic exchange, or thermal contrasts between isolated pools and the flowing portion of a stream. In addition, lakes, ponds, and wetlands can produce elevated water temperatures at their outlets, resulting in downstream cooling below them over distances of hundreds of meters, even through cut blocks (Mellina et al., 2002).

Fewer studies have examined stream temperature response to forest harvesting in snowmelt-dominated regimes, and no published studies employed a BACI design to estimate effects of no-buffer harvesting in these environments.

The protective effect of the buffers was compromised by significant blowdown, which reduced riparian canopy density from about 35 percent to 10 percent at one high retention buffer and from about 15 percent to less than 5 percent at one low retention buffer (Macdonald 2003) Mellina et al. (2002) documented temperature responses to clear-cut logging with riparian buffers for two lake headed streams. Both streams cooled in the downstream direction both before and after logging. The dominant downstream cooling observed both before and after harvest was attributed to the combination of warm source temperatures associated with the lakes and the strong cooling effect of ground water inflow through the clear-cut, as well as the residual shade provided by the partially logged riparian buffer.

Temperature increases in headwater streams are unlikely to produce substantial changes in the temperatures of larger streams into which they flow, unless the total inflow of clear-cut heated tributaries constitutes a significant proportion of the total flow in the receiving stream- Clear Cr minimizes harvest to remain within ECA thresholds thereby not affecting stream power or increasing channel instability and base flows significantly.

Based on the available studies, a one-tree-height buffer on each side of a stream should be reasonably effective in reducing harvesting impacts on both riparian microclimate and stream temperature

Smaller low order streams may be especially sensitive to timber removal. Hydrologic changes may be additive in higher order streams.

"Hydrologists should consider the potential modifications to headwater basins in scheduling harvest entries and locating harvest units, especially when conditions are such that the stream system is likely to be sensitive to streamflow modification."

King, J.G. 1989. Streamflow responses to road building and harvesting: a comparison with the equivalent clearcut area procedure. U.S. Dep.Agric. For. Serv., Ogden, Utah. Res.Pap. INT-401.

Steam temperature and stream volume are related, and changing the thermal input or water volume can alter overall stream temperature.

"Since stream temperature is a measure of the amount of heat energy per unit volume of water, changing either the amount of heat energy entering the stream or the amount of water flowing in the channel has the potential to alter stream temperature. Further, since a diversity of physical processes in the stream channel, riparian zone, and alluvial aquifer influence the temperature of water in stream systems, degradation of stream temperature can result from modification of external drivers as well as modification of the internal structure of the integrated stream system."

Effects of uplandland vegetation can be important to stream temperature. Increased sediment can increase water temperatures by decreasing streambed conductivity and reducing connection to groundwater.

"Whether the catchment of a stream is urban, forested, rangeland, or agricultural, disturbance of upland vegetation associated with human activities has the tendency to increase sediment delivery, warm lateral water inputs, alter the relative amount of surface runoff (and therefore, peak flows), and alter upland water infiltration and groundwater recharge (Naiman and others
1992, National Research Council 1996). When considering stream channel temperature, perhaps the most pervasive and best studied effect of upland land use is the change in channel morphology (usually widening and shallowing of channels) in response to increased sediment load (Dose and Roper 1994, Knapp and Matthews 1996, Richards and others 1996, Sidle and Sharma 1996). Wider channels have greater surface area and are not as easily shaded by riparian vegetation, thereby facilitating the exchange of heat with the atmosphere. Increasing sediment load can also clog coarse streambed gravels with fine sediments (Megahan and others 1992), thereby decreasing streambed conductivity and reducing the exchange of groundwater and surface water across the streambed (Schälchli 1992)."

Table 3. Relative influence of stream characteristics on temperature in small, medium, and large streams

	Stream characteristics				
Stream Order	Riparian shade	Stream discharge	Tributaries	Phreatic groundwater	Hyporheic groundwater
1–2	High	Low	Moderate	High	Low–Mod
	Riparian shade and lateral phreatic groundwater inputs provide thermal stability. Lateral tributaries can frequently affect overall stream temperature. Large wood stores sediments and creates streambed complexity, driving hyporheic flow. (However, hyporheic influence is high and shade moderate in alpine meadow systems.)				
3–4	Moderate	Moderate	High	Moderate	Mod–High
	Temperature of lateral tributaries has strong influence on stream temperature. Effects of riparian shade modest. Thermal inertia due to larger flows becomes more important. Where floodplains form, channels patterns become more complex, and alluvial aquifers are well developed, hyporheic influence can be high. Large wood creates habitat complexity and forms channel-spanning jams that may provide significant shade to the stream.				
5+	Low	High	Low–Mod	Low–Mod	Mod–High
	Complex floodplain morphology creates a diversity of surface and subsurface flow pathways with differential downstream flow rates allowing for stratification, storage, insulation, and remixing of waters with differential temperatures. The resulting mosaic of surface and subsurface water temperatures continually remix to buffer channel temperature and create thermal diversity. The thermal inertia of large water volumes allows the stream to resist changes in temperature. Where side channels exist, shade from vegetation can be important.				

Poole, Geoffrey C. and Berman, Cara H. 2001. An Ecological Perspective on In-Stream Temperature: Natural Heat Dynamics and Mechanisms of Human-Caused Thermal Degradation. Environmental Management Vol. 27, No. 6, pp. 787– 802.

Describes process of stream heating including hyporheic flow…in regards to upland vegetation management, it focuses on the need to assess the specific pathways by stream morphology and processes that affect temperature…cites channel widening resulting from increased sediment load is the most pervasive and studied effect of upland use on stream temperatures. Sediment load from riparian veg disturbance and reduction of bank stability…also removal of buffering vegetation. Engineered channels greatly affect time and surface area floodwaters have to be absorbed into the aquifer (i.e. lower Clear Cr) and typically lack heterogeneity in channel pattern and streambed topography thereby reducing hyporheic flow.

Removal of upland vegetation reduces phreatic groundwater and discharge by decreasing infiltration of groundwater on hillslopes and reduces baseflow in streams. [Other studies say harvest increases base flows for a couple of years then goes back to normal]

Restoration of geomorphic channel structures, channel-forming processes, sediment dynamics, and flow regimes (Poff and others 1997, Stanford and others 1996) may be critical to the reestablishment of historical temperature regimes in streams.

Cites older studies (1970s,80s, 90s) that do not implement current management practices.
Also based on other studies above, the substrate is not made up of fine sediments, therefore the likelihood of temperature increases in minimized since fine substrates reduce the flow and can lead to temperature increases. Large substrates (gravels/cobbles) are less likely to cause increases as the flow can easily move through them. RHCAs have not been heavily managed so the structure is in place to provide for natural temperatures (have not been greatly modified by activities…except the SF which burned twice)

Stream temperatures in the Western United States are increasing rapidly. Salmonid populations which are already depressed due to fragmentation and management may be vulnerable.

"A growing number of studies predict substantial disruptions to aquatic ecosystems from climate change within the northwest U.S. (Battin et al. 2007; Rieman et al. 2007; Crozier et al. 2008; Schindler et al. 2008; Isaak et al. 2010a; Mantua et al. 2010; Wenger et al. 2011a) and more broadly (Eaton and Schaller 1996; Keleher and Rahel 1996; Mohseni et al. 2003; Hari et al. 2006; Heino et al. 2009). The trends in river and stream temperatures we document, in combination with increasing evidence of thermal constraints on some populations (Cooke et al. 2004; Goneia et al. 2006; Sutton et al. 2007; Keefer et al. 2007; Doremus and Tarlock 2008; Keefer et al. 2009), suggest these predictions are being realized. Although most species have persisted through greater climatic perturbations in past millennia, modern climate change is happening especially rapidly, at the end of an already warm period, and is being imposed on populations that are often already depressed and fragmented from a century of intense human development (McIntosh et al. 2000; Hessburg and Agee 2003)."

Isaak, D. J., S. Wollrab, D. Horan, and G. Chandler (2012), Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes, Clim. Change, 113, 499–524, doi:10.1007/s10584-011-0326-z.

Climate Shield being used for cold water native species, not just bull trout. Federal lands will play an important role in conservation and protection of cold water for native species.

"Most of these coldwater habitats occur on federal lands at higher elevations, particularly the National Forests. Future climate change will enhance this pattern, emphasizing the role that federal land management can play in maintaining a climate shield to conserve native coldwater species."

Isaak, Daniel J.; Young, Michael K.; Nagel, David; Horan, Dona. 2014. Cold water as a climate shield to preserve native trout through the 21st Century. In: Carline, R. F.; LoSapio, C., eds. Looking back and moving forward: Proceedings of the Wild Trout XI Symposium; Sept 22-25, 2014; West Yellowstone, MT. Bozeman, MT: Wild Trout Symposium. p. 110-116.

Streams not influenced by direct warming from thermal radiation may be vulnerable to other factors regulated by hydrology. Riparian disturbance, decreased summer flows, decreased groundwater may prove to be more important for these streams.

"The strong pattern of cold streams being less sensitive may only hold for direct warming through radiative transfer. Some of the streams identified as low sensitivity may be vulnerable to secondary influences of climate change regulated *by hydrology, such as riparian disturbance (e.g., fire or debris flows), earlier snowmelt (with decreased summer flows), or decreased groundwater recharge*. The estimates of thermal sensitivity provided here may provide useful context for contrast with warming estimated through other processes."

Luce, C. H., Staab, B., Kramer, M., Wenger, S., Isaak, D., and Mc-Connell, C.2014: Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest,Water Resour. Res., 50, 3428–3443, doi:10.1002/2013WR014329.

Climate change and land cover disturbances can increase ground water temperatures and therefor also increase stream temperature.

"We have suggested in this study that although seasonal surface-temperature changes are damped in the shallow subsurface, long-term changes in surface temperatures can be propagated to much greater depths. This phenomenon has been known for some time in the field of thermal geophysics (e.g., Lesperance et al., 2010), but it is generally overlooked in stream temperature modeling."

"Previous studies have identified the potential importance of considering shallow groundwater temperature warming when projecting future stream temperature (Kurylyk et al., 2013, 2014a)."

Kurylyk, B. L., MacQuarrie, K. T. B., Caissie, D., and McKenzie, J. M.: Shallow groundwater thermal sensitivity to climate change and land cover disturbances: derivation of analytical expressions and implications for stream temperature modeling, Hydrol. Earth Syst. Sci., 19, 2469-2489, https://doi.org/10.5194/hess-19-2469-2015, 2015.

Kurylyk et al 2013*: Results from the empirical transfer function indicated that the change in groundwater temperature will exhibit seasonality at shallow depths (1.5 m), but be seasonally constant and approximately equivalent to the change in the mean annual surface temperature at deeper depths*
(8.75 m). The increases in future groundwater temperature suggest that the thermal sensitivity of baseflow-dominated stream to decadal climate change may be greater than previous studies have indicated,,,New Brunswick Canada

GST (ground surface temp)- decrease in winter, MAGST changes are damped with respect to MAAT
MAGST (mean annual GST)
MAAT (mean annual air temp)
GWT (ground water temp)- shallow (1.5m) is sensitive to increases in air temp; exhibit seasonality at shallow depths (1.5m), seasonally constant and about equivalent to the change in MAST at deeper depths (8.75m); will respond to increasing AT and GST from decadal climate change
AT(air temp)

This study has also demonstrated the limitations inherent in predicting future climate change impacts using a single projected climate series based on one emission scenario, simulated with one GCM, and downscaled using only one approach. Climate modelling involves many assumptions and, as such, an array of climate scenarios should be considered.

We have also demonstrated that baseflow-dominated streams may be more sensitive to climate change than existing seasonally-derived thermal sensitivities, based on weekly air and stream temperature data, may indicate. Salmonids are threatened by rising river temperatures in eastern North America

Kurylyk et al 2014*: The thermal sensitivity formulae suggest that shallow groundwater will warm in response to climate change and other surface perturbations, but the timing and magnitude of the subsurface warming depends on the rate of surface warming, subsurface thermal properties, bulk aquifer depth, and groundwater velocity*

indicate that the soil thermal properties greatly influence the subsurface thermal response to seasonal temperature variability. In particular, due to the significantly lower thermal diffusivity of partially saturated peat (Table 2), the surface-temperature signal is more quickly damped in the peat soil (Fig. 6c) in comparison to the results obtained for sand (Fig. 6a) and clay (Fig. 6b). However, in each of the nine scenarios presented in Fig. 6, the parameter is less than 0.2 (amplitude reduced by at least 80 %) when the depth is greater than 5 m, which indicates that groundwater discharge does not have to be sourced from a very deep aquifer to decrease the stream thermal sensitivity to seasonal air temperature changes

Beyond the depth of seasonal temperature fluctuations (Fig. 5), groundwater temperature will still be influenced by long-term surface-temperature perturbations

Changes to mean annual surface temps of 2C was observed by Lewis (1998)

Thus, for initially uniform conditions, deeper aquifers will generally remain colder longer than shallow aquifers, as it takes longer for the warming signal to be advected or conducted downwards. Furthermore, Fig. 7a also indicates that soils with a higher thermal diffusivity (i.e., sand) will initially transport the surficial warming signal through the subsurface more rapidly than soils with lower thermal diffusivity (i.e., peat).

In the case of vegetation regrowth, the surface-temperature warming due to the land cover disturbance would be temporary

For example, the maximum groundwater warming (0.88 _C) for the peat soil at a depth of 20m occurs at 33 years, which is 8 years after the surface warming has ceased. Thus, thermal impacts to coldwater streams caused by deforestation may persist several years after vegetation regrowth has occurred, particularly if groundwater discharge to the stream is sourced from a deeper aquifer. However, these effects would likely not be significant as the warming signal would be strongly damped at such depths.

small headwater streams, which are often groundwater dominated, can warm more rapidly than larger streams in response to deforestation because, for natural vegetative conditions, smaller streams typically experience more shading than larger rivers (e.g., Caissie, 2006

small streams are generally very dependent on groundwater inputs and temperatures, and their low thermal capacity (shallow depth and volume) makes them very vulnerable to any surface or subsurface-energy flux modifications (e.g., Matheswaran et al., 2014). This has been shown in many timber harvesting studies, where the smallest streams have experienced the greatest increase in stream temperature following forest removal (e.g., Brown and Krygier, 1970).

Lethality

All of the lethal temperatures referenced in this section can be found in Table 11. WDOE (2002) reviewed literature on three types of studies (constant exposure temperature studies, fluctuating temperature lethality studies, and field studies) and used this information to calculate the MWMT that, if exceeded, may result in adult and juvenile salmonid mortality. The resultant MWMTs for these various types of studies are as follows: constant exposure studies 22.64°C, fluctuating lethality studies 23.05°C , and field studies 22.18°C.

Table 11: Effects of Temperature in Considering Lethality and Salmonids

°C	Steelhead	Chinook	Coho	All Salmonids
28			28 LT50[1] for age 0-fish acclimated to a 10-13C cycle (6)	
27				
26			26 LT50[1] for presmolts (age 2-fish) acclimated to a 10-13C cycle (6)	
25		25.1 Upper lethal temp. at which 50% of the population would die after infinite exposure, juvenile Chinook acclimated to temperatures from 5-24C (4)	25.6 Upper lethal threshold (3)	
		25 Upper lethal threshold (3)	25 Upper lethal temp. at which 50% of the population would die after infinite exposure, juvenile coho acclimated to temps. from 5-24C (4)	
		25 Chronic (exposure >7 days) upper lethal limit for juvenile Chinook (5).		
24		24-24.5 Survival becomes less than 100% for juvenile Chinook acclimated to temperatures from 5-24C (4)		
23	23.9 Upper lethal threshold for steelhead (3)			23.05 do not exceed this value to prevent adult and juvenile mortality, data from fluctuating temp. studies (1)
22				22.64 do not exceed this value to prevent adult and juvenile mortality, data from constant exposure studies (1)
				22.18 do not exceed this value to prevent adult and juvenile mortality, data from field studies (1)
21	21.1 Temperature lethal to adults (7)			
	21 Lethal threshold for steelhead acclimated to 19C (2)			

[1] Maximum temperature in the cycle at which 50% mortality occurred

References

1 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
2 Coutant (1970, as cited by USEPA 1999)
3 Bell 1986 (reviewed many literature sources to make assessments of temperature needs)
4 Brett 1952 (laboratory study)
5 Myrick and Cech 2001 (reviewed many literature sources to make assessments of temperature needs)
6 Thomas et al. 1986 (laboratory study)
7 CDFG 2001 (reviewed literature sources to make assessments)

Carter, K. (2005, August). The effects of temperature on Steelhead Trout, Coho Salmon, and Chinook salmon biology and function by life stage. Retrieved November 12, 2016, from California Environmental Protection Agency; State Water Resources Control Board. 26pp.

<u>Lethal temperatures for salmonids can vary greatly. However, temperatures above 24ºC can be lethal for juvenile steelhead. Temperatures should remain below 19º to 20ºC to protect steelhead from temperature related mortality.</u>

Nielson et al (1994) reported upper lethal temperature at 24ºC for Juvenile steelhead. Redding and Schreck (1979) reported mortalty within 20.5h for fish acclimated to 12ºC rapidly raised to 26.5ºC. Coutant (1970) reported for steelhead taken during the peak adult migration in the Columbia, the incipient lethal temperature was 21º-22ºC. Hicks (2000) recommended that daily maximum temperatures remain below 19º to 20ºC to prevent directly lethal conditions to steelhead.

Richter, A., and S. A. Kolmes. 2005. Maximum temperature limits for Chinook, coho, and chum salmon and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13:23–49.

__General thoughts- K. Smith:__

Studies cited mostly cite studies from harvest pre-PACFISH or those done on private or state lands, most of which included riparian harvest. This is not representative of the Clear Cr project design features.

Based on larger substrates and stream morphology (step-pool), hyporheic flow is not likely to contribute to stream warming. The flow is important for cooling and based on substrate, morphology, and little harvest in RHCAs, it isn't likely to be affected by management activities.

Because sediment loading can affect it by filling the interstitial spaces, then road improvement and decommissioning should reduce the amount of management related sediment in streams over time.

The project is designed to moderate the effects of large wildfires when they occur. As evidenced in Swiftwater Cr after the JBar fire, landslides will occur and can both add, and remove sediment from the stream system. If sediment at the hatchery is a concern, then proposed harvest treatments are likely warranted in order to reduce the landslide risk and subsequent delivery to streams and the hatchery.

Isaak et al…2010…effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network…Ecological Applications 20(5), pp. 1350-1371

Boise River Basin Study: During our study period, basin average mean stream temperatures increased by 0.388C (0.278C/decade), and maximas increased by 0.488C (0.348C/ decade), primarily due to long-term (30–50 year) trends in air temperatures and stream flows. Radiation increases from wildfires accounted for 9% of basin-scale temperature increases, despite burning 14% of the basin. Within wildfire perimeters, however, stream temperature increases were 2–3 times greater than basin averages, and radiation gains accounted for 50% of warming. Thermal habitat for rainbow trout (Oncorhynchus mykiss) was minimally affected by temperature increases, except for small shifts towards higher elevations. Bull trout (Salvelinus confluentus), in contrast, were estimated to have lost 11–20% (8–16%/decade) of the headwater stream lengths that were cold enough for spawning and early juvenile rearing, with the largest losses occurring in the coldest habitats. Our results suggest that a warming climate has begun to affect thermal conditions in streams and that impacts to biota will be specific to both species and context. Where species are at risk, conservation actions should be guided based on considerations of restoration opportunity and future climatic effects

Rainbow trout habitats encompassed much of the stream network in 1993 and the total amount of estimated habitat was not substantially affected by warming trends. The most notable changes were small habitat gains at higher elevations (sometimes accelerated within wildfire perimeters) as unsuitably cold areas became thermally suitable. Bull trout natal habitats, in contrast, initially encompassed approximately half the BRB stream network and experienced systematic declines because these areas already occurred at the upper terminus of the network and losses in low-elevation sites were not offset by gains farther upstream (Table 5, Fig. 6). The total length of thermally suitable stream based on mean temperature criteria decreased by 11–20% (8–16%/decade), and the size of remaining natal patches was reduced by 10–18%. The greatest reductions occurred within wildfire perimeters and for the coldest, high-quality habitats because these areas comprised a smaller area at the outset of the study and changes relative to this baseline were amplified